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Rotating solar photobioreactor for use in the production of algal biomass from gases, in particular CO2-containing gases

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(54) Title: ROTATING SOLAR PHOTOBIOREACTOR FOR USE IN THE PRODUCTION OF ALGAL BIOMASS FROM GASES, IN PARTICULAR CO_2-CONTAINING GASES

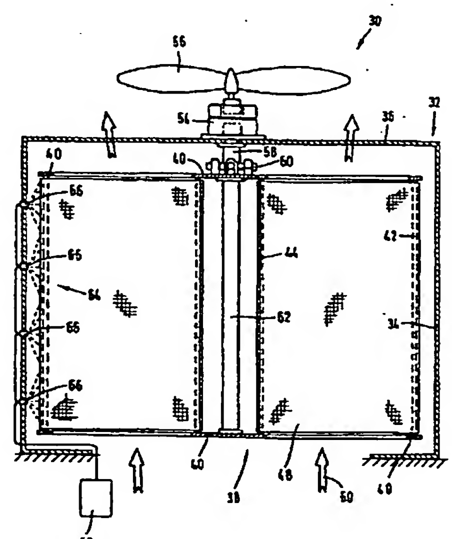
(54) Bezeichnung: ROTIERENDER SOLAR-PHOTOBIOREAKTOR ZUR PRODUKTION VON ALGENBIOMASSE AUS INSBESONDERE KOHLENDIOXIDHALTIGEN GASEN

(57) Abstract

The proposed solar photobioreactor for use in the production of algal biomass from gases, in particular CO_2-containing gases, is provided with a frame (32) which carries a gas-permeable algal substrate (48) which can rotate about an axis (62) of rotation and can be exposed to predominantly laterally incident diffuse or direct sunlight. A drive unit (54) is provided for rotating the algal substrate (48) and a nutrient medium feed device (64) is provided for applying a nutrient medium to the algal substrate (48).

(57) Zusammenfassung

Der rotierende Solar-Photobioreaktor zur Produktion von Algenbiomasse aus insbesondere kohlendioxidhaltigen Gasen ist mit einem Gestell (32) versehen, welches ein um eine Drehachse (62) drehbar gelagertes gasdurchlässiges Algensubstrat (48) trägt, das dem vorwiegend seitlich einfallenden diffusen oder direkten Sonnenlicht aussetzbar ist. Ferner sind eine Antriebsvorrichtung (54) zum drehenden Antreiben des Algensubstrats (48) und eine Nährmedium-Zuführvorrichtung (64) zum Benetzen des Algensubstrats (48) mit einem Nährmedium vorgesehen.



ABSTRACT

Rotating Solar Photo Bioreactor for Use in the Production of Algal Biomass from Gases, in Particular CO_2-Containing Gases

The rotating solar photo bioreactor for producing algal biomass especially from gases containing carbon dioxide is provided with a frame (32) supporting an algal substrate (48) which is permeable to gas and rotatable about a rotational axis (62) and can be exposed to diffuse or direct sunlight mainly impinging laterally. Furthermore, a driving means (54) for rotatably driving the algal substrate (48) and a nutrient medium supply means (64) for humidifying the algal substrate (48) with a nutrient medium are provided.

(Fig. 3)

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Rotating Solar Photo Bioreactor for Use in the Production of Algal Biomass from Gases, in Particular CO_2-Containing Gases

The present invention relates to a rotating solar photo bioreactor for producing algal biomass especially from gases containing carbon dioxide.

The various embodiments of photo bioreactors for producing algal biomass have various sizes and range from open systems to closed ones, from sophisticated controlled arrangements to simple basins. The economy of such arrangements is predominantly determined by the high-quality products to be obtained from the cultivated algal biomass or by cleaning contaminated water by means thereof. Prior art photo bioreactors are not primarily designed to clean exhaust gases using their content of carbon dioxide.

A significant problem of photo bioreactors consists in the photo inhibition of the algae when they are exposed to light for too long a period. For a constant photosynthesis, it is necessary to shade off the algae intermittently. In the prior art, this is obtained, for example, by the algae circulating in a suspension, thereby being shaded off intermittently. Such photo bioreactors can only be operated with mechanically insensitive algae, as the algae are subject to mechanical stress, especially to shearing forces, when being circulated and/or revolved.

When the algae are permanently exposed to light, a photo inhibition of the algae occurs in the surface area, so that these algae only make a small contribution to the production of algal biomass. Only the algae in the deeper layers can keep growing effectively, thereby producing algal biomass. A thick algal substrate therefore comprises a relatively large content of algae which do not contribute to the production of algal biomass, which is why the efficiency of these photo bioreactors is limited.

It is the object of the present invention to increase the efficiency of solar bioreactors for producing algal biomass.

To achieve this object, the invention discloses a rotating solar photo bioreactor comprising

- a frame,
- an algal substrate for algae, which is pivoted about a rotational axis and whereon the algae remain during the growth thereof and which is intermittently exposable to sunlight of varying intensity,
- a driving means for rotatably driving the algal substrate, and
- a nutrient medium supply means for supplying a nutrient medium to the algal substrate.

In the device according to the invention, the algal substrate permeable to gas is rotatably arranged on a frame. The algal substrate is put into rotation about a central axis by means of a driving means. In this context, it should be noted that the driving means can be formed as a separate element or can be an integral component of the algal substrate, as it were, which is then formed such as to convert the wind and/or the flow of gas and/or a supplied medium or liquid it is subject to into rotational energy. The supply means provides the algal substrate with a nutrient medium.

The fact that the algal substrate rotates is decisive for the invention. Thereby, the individual surface areas of the algal

substrate are alternately exposed to the preferably laterally incident sunlight of varying intensity and, because of the design, are shaded off or exposed to diffuse sunlight (dim light). This increases the efficiency of the algae production in a decisive manner, as the photosynthesis systems of the algae responsible for converting sunlight can regenerate in the shading time intervals or the intervals during which they are exposed to diffuse sunlight so as to be available for sunlight conversion afterwards. The algae remain on the substrate during their entire growth period. Thus, a permanent reimplanting of the substrate with algae held in suspension in a revolving or circulating system is not provided until harvesting takes place. The algae are only separated from the substrate when being harvested, for example by means of a controllable desorption. Thus, for instance, a desorption liquid can be put onto the algal substrate (via the nutrient medium supply means). At this time, no nutrient medium gets onto the substrate via the supply means. Alternatively, a separate deposition or supply means can be provided for depositing the desorption medium onto the algal substrate.

Preferably, the algal substrate is formed in the shape of a fan with lamellas, thus comprising an extremely large surface, and is especially formed in the shape of an impeller with sheet material arranged in a zigzag shape. In this arrangement, the individual lamellas of the algal substrate sheet material shade off one another and are intermittently exposed, holohedrally and with varying intensity, to the sunlight. This intermittent irradiation by preferably laterally incident sunlight is determined by the arrangement or the construction and circulation of the algal substrate.

It should be noted here that the rotating solar photo bioreactor is completely exposed to the sun, which especially applies to the algal substrate. Alternatively, it is possible to introduce the rotating algal substrate into a translucent or partially open housing so that the algal substrate is always sequentially exposed completely to the sunlight and shaded off once per rotation thereof.

Thus, by means of the invention, it is possible to use algal substrates with layers as thin as possible, of 0.1 mm to 5 mm, on which the algae remain during the course of their growth and thus during the production of algal biomass, i. e. until being harvested. The photo inhibition of the algae on the thin algal substrate is avoided in the design, as the algal substrate is formed such that it is intermittently exposed to sunlight of varying intensity in certain areas by shading off itself. Thus, the invention does not provide a circulating or permanently rotating algae suspension. The choice of algae to be employed in the photo bioreactor according to the invention is therefore extended, as algae which are sensitive to mechanical stress may be employed as well.

The photo bioreactor according to the invention optimizes the use of gases containing carbon dioxide, especially exhaust gases, for increasing the production of algal biomass by using sunlight. This process is not primarily used to produce high-quality pure products but especially to use the obtained biomass as an energy carrier by burning it or by employing it in the production of biodiesel or biogas. Burning these products to obtain usable energy provides exhaust gases, which can be used to produce algal biomass in a recycling system.

As an advantageous improvement of the invention, it is further provided that the algal substrate comprises a support structure in the shape of a hollow cone. Irrespective of the design thereof, this should be impermeable to gas so that gas can always flow through the algal substrate supported by the support structure, which especially consists of thin sheet material (nonwoven fabric or the like, e. g. with a strength of 0.1 mm to 5 mm).

The carrier structure especially comprises a cage with two face walls connected by exterior and interior rods. The sheet material extends between these exterior and interior rods especially in a zigzag shape and is thereby supported by the cage. This design, in which the cage is especially cylindrical

in shape, makes it possible to arrange algal substrate sheet material both creating an extremely large surface area and requiring a minimum amount of space.

Furthermore, it is suitable if the nutrient supply means is fixed on the frame as a unit with the algal substrate moving past it. In this manner, the entire surface of the algal substrate is wetted by nutrient medium once per turn. The nutrient supply means is especially formed as a spraying means for spraying nutrient medium on the algal substrate.

Preferably, the algal substrate is suspended on gimbals on its rotational axis on the frame so that it can oscillate freely during rotation, which is advantageous with regard to the prevailing wind (the algal substrate is especially exposed, freely and on all sides, to the sunlight and thus to the environment).

The algal substrate reactor can be arranged freely and thus does not have to be surrounded by a building or the like. If such a building is used, it should comprise at least one section (an opening or a transparent wall member, both especially provided with optical members for capturing light, such as lenses, prisms and the like) transparent to sunlight the algal substrate passes by. Even in this case, the individual areas of the algal substrate are exposed to light of varying intensity.

In the case mentioned above, in which the algal substrate is surrounded by a building which is provided, in a certain area, with at least one opening or one transparent wall member (both especially provided with optical members, such as lenses, prisms and the like), it is also possible that the building rotates (slowly) to track the position of the sun according to the time of the day.

The rotational axis about which the algal substrate rotates can be arranged horizontally, vertically or in a spatially inclined manner. The planes the algal substrate extends in are

arranged especially parallel to the rotational axis. The algal substrate is especially formed in the shape of an impeller, the blades whereof are arranged substantially radially and are formed by the algal substrate or covered with it.

The photosynthesis of the algae causes the carbon dioxide from a wide variety of combustion processes to be bound chemically. The use of fossile fuels, which is questionable for climatic reasons, can be replaced successively by regenerative energy from biomass within the framework of the same existing technology with the percentage of the algal biomass in the fuels being successively increased. The biomass obtained per unit area is far larger in the case of algae than in the case of higher plants and can even be increased further by exhaust gases. The remaining heat of the exhaust gases is also used.

In the reactor disclosed herein, carbon dioxide, for example from exhaust gases, can be supplied to the algae in the best possible way to increase productivity in comparison with conventional bioreactors; the algae are also provided with sufficient photosynthetically active radiation (PhAR). It is avoided to a far extent that the radiation is too strong, and the individual algae cells are kept from shading off one another permanently and from desiccating or overheating. The harvesting method of the biomass is preferably integrated in the system. The yield per unit area is additionally increased by a partially vertical arrangement of the reaction surfaces. Direct and diffuse sunlight are used. The system can easily be adapted to the position of the sun according to season and time of day as well as to latitude or special circumstances of the location. The design is suitable for open-air and greenhouse use and requires comparatively little investment capital. It is possible to scale up the arrangement for power plant use. An optional modular combination of multiple reactors can improve a fail-safe permanent use of the arrangement. The use of environmentally friendly materials and the combined use of other regenerative energies is possible.

The most suitable substrate for the algae is a sheet material which is chosen according to the algae to be used and the products to be obtained. The sheet material forms the reactor surface used as a substrate by the algae. It should therefore be transparent to light and permeable to gas and should comprise a certain surface roughness to increase the substrate surface. A certain absorbency is desirable to reduce the technical requirements to uniformly humidify the reactor surface. A good distribution of humidity is obtained by capillary action in nonwovens or fabrics. The size of the capillary spaces and the characteristics of the surface of the material have to be adapted to the substrate requirements of the algae to be employed, such that an adhesion is obtained and the algae are not washed out when a medium is added. However, this surface has to allow for the algae to be harvested therefrom. Resistance against UV radiation and wear are further limiting conditions for a cost-effective permanent use. Apart from that, the energy balance of the production and the natural ability of the materials to be decomposed or recycled is interesting what the ecological balance of the reactor is concerned. As raw materials, polyethylene (PE), polypropylene (PP), polyester (PES) and polyacrylic appear suitable. When the substrate surfaces are arranged properly, a high absorbency can further minimize the pumping processes required to distribute liquid and thus contribute to an even more positive energy balance. If nonwovens are used to produce algal substrates, the main component should consist of PP or PE, which are energy and cost efficient, and PES or polyacrylic can be added as an absorbent component. Compared to that, natural fiber products available today are interesting what the decomposability is concerned, but have a relatively unfavorable energy and cost balance.

Improvements on the prior art due to the rotating solar photo bioreactor algal substrate for producing algal biomass are:

1. high energy productivity per unit area in the form of usable biomass

2. low amount of energy input (for operation, harvesting and material)

3. quality of energy input (integrated use of other regenerative energy carriers)

4. ability to be integrated with existing technologies using fossile energy carriers

5. low-cost operation and investment

6. integrated harvesting method, low labor requirements, possibility of automation

7. operating reliability, regional adaptability, easy scale-up.

Optimization	Technical solution
Avoiding permanent self-shading	Rotation and 3D-alignment of a thin layer reactor, vertical substrate sheet material with large surfaces
Uniformly using direct light	Rotation of thin layer substrate
Avoiding photo inhibition	Rotation of thin layer substrate
Uniformly using diffuse light	Rotation of thin layer substrate
Using strobe light effect	Rotation and lamellar shape of thin layer substrate
Avoiding photo respiration	Use of exhaust gases, high CO_2 concentration, low O_2 concentration when exposed to light
Optimum supply of nutrients	Continuous or discontinuous supply of medium, thin layer system

Reducing gas diffusion paths and increasing physiological availability of CO_2	Thin layer system with internal (and optionally external) supply of gas or CO_2 solutions in a humidifying medium, especially the nutrient medium, for the algal substrate
Optimizing the temperature	Cooling the exhaust gases or adapting the temperature of the medium, possibly using the remaining heat from the exhaust gas
Amplifying the spectral range of the photosynthetic light	Proper choice of algae and/or use of spectral filters

Optionally: closing the green light spectral gap by the proper choice of algae.

What economy, ecology, operating reliability and adaptability are concerned, the following characteristics of the solar photo bioreactor according to the invention can be named:

- low energy requirements (quantitative energy input)
- possibility for integrated use of regenerative energy carriers (wind, water, sun; qualitative energy input)
- smaller area intensity by increasing the efficiency of the photosynthesis per unit area
- integrated harvesting possibilities by drying on the reactor surface, desorption in a dipping bath
- operating reliability, regional adaptability, easy scale-up by modular construction
- low investment costs by proper choice of material
- ecologically neutral system possible by using a high percentage of regenerative or recyclable materials

There now follows a more detailed description of embodiments of the invention with respect to the drawings.

Fig. 1 shows a schematic diagram of the construction of a solar photo bioreactor with an algal substrate ar-

ranged in the shape of a hollow cone according to a first embodiment of the invention,

Figs. 2 and 3 show longitudinal and transverse cross-sectional views of a solar photo bioreactor according to a second embodiment of the invention in an algal substrate arranged in a zigzag or star shape and supported by a cage, and

Fig. 4 shows a top plan view of a solar photo bioreactor according to a third embodiment characterized in that the support structure for the algal substrate comprises multiple cassette supports for cassette inserts whereon an algal substrate is tentered which has a semicylindrical shape due to the cassette inserts so that it can contribute to the rotation of the support structure by using wind energy or other flows.

The reactor 10 according to Fig. 1 has the shape of a rotating cone 11. In the simplest embodiment, the envelope of cone is covered by a material 12 which forms the reaction surface exposed to light and is humidified with a nutrient medium on both sides (indicated at 13). The material 12 is permeable to gas, ranges from bright to transparent and represents the algal substrate whereon the algae supplied with nutrient medium and gas containing CO_2 grow. The warm exhaust gas 14 is guided into the interior of the cone and rises in the cone, one part flowing through the substrate 12 past the algae and the other part leaving the cone 11 through an opening 15 on the upper side. The cone 11 is pivoted in the extension of its axis 16 on a frame 17 (just indicated). The rotation provides that, light, carbon dioxide, nutrient medium and algae are distributed in an optimum way. Excess nutrient medium and suspended algae drip from the substrate 12 into a flat funnel 18 from where they get into a settling basin 19. The settling basin 19 comprises an outlet 20 draining the suspended algae. Furthermore, the settling basin 19 feeds into a nutrient medium circulation conduit 21 which feeds the excess nutrient medium to-

gether with nutrient medium from a supply container 22 connected to the circulation conduit 21 to the upper end of the cone 11 to discharge it there. A pump 24 takes in the excess nutrient medium and medium from the supply container 22. CO_2, for example from exhaust gases, can be added to the nutrient medium. Near the settling basin 10 in the circulation conduit 21, there is an algae filter 23 to keep algae away from the nutrient medium circulation system.

As an alternative, the supply of the medium can be adapted to the water and nutrient consumption such that it is adsorbed almost completely on the reaction surface. In this case, a reception funnel and a circulating nutrient medium flow are not necessary.

The shape of the reactor can be determined by the distance and the circumference of two rings arranged on the ends of the hollow cone and cross-struts of the support structure 25 supporting the sheet material, which form the frame for the reaction surfaces which consist of the material mentioned above and are fixed to these rings. The alignment of the reaction surface to the angle of incident sunlight or incident diffuse light can thereby be optimized.

The biomass is harvested differently according to the kind of algae used:

1. by electrical or chemical desorption of the algae,

2. by stripping the algae off the (wet) surface, or

3. by stripping off the algae, separating components to be used or by renewing the surface, after the reactor has rotated for a period of time in a dry state without further nutrient medium having been supplied.

In the process of chemical desorption, the nutrient medium circulation system is used to feed pure desorption liquid to the algal substrate. For this purpose, the circulation conduit

21 is sealed off via a valve 26 arranged between the pump 24 and the conduit 27 from the nutrient medium supply container 22. A conduit 27' feeds into the circulation conduit 21 between the pump 24 and the valve 26, which conduit 27' can be sealed off by a valve 28. When the valve 28 is open, the circulation conduit 21 is connected to a desorption liquid supply container 29 via this conduit 27'. When the valve 28 is open and the valve 26 is closed, the pump 24 takes in desorption liquid from the supply container 29. This desorption liquid is fed onto the algal substrate, whereby the algae are solved from the substrate 12 and get into the settling basin 19 together with the desorption liquid, from where they can be drained and thus harvested via the outlet 20.

The driving energy for rotating the reactor and for operating the pump can be obtained from the warm exhaust gases rising in the cone 11, from wind and solar energy or from any possible combination thereof. Because of the danger of desiccation due to wind or because of the danger of photo inhibition due to too strong solar radiation, the supply of the medium and the rotation of the reactor can be varied.

The structure of the envelope of the cone can be changed in a derived form to increase the surface and to increase the permeability to gas such that the envelope of cone consists of many centripetally arranged thin lamellas or cassettes each leading from the upper attachment ring to the lower one. When their alignment to the cone axis is turned such that they are arranged similar to the rotor blades of a Savonius rotor, such an outdoor reactor is able to take in rotational energy from the wind. The structure suspended on gimbals allows to align the top side of the reactor in the direction of the wind when the wind is strong, thereby minimizing the working surface of the wind and the resistance to flow of the reactor.

A second embodiment of a reactor 30 is represented in Figs. 2 and 3. The reactor 30 comprises a frame 32 comprising some vertical struts 34 arranged at an equal pitch and horizontal struts 36 connecting these to one another and in which a sub-

stantially cylindrical body of rotation 38 is arranged to oscillate and to rotate. The body of rotation 38 comprises, on the end faces thereof, members 40 which are permeable to gas and between which exterior supporting rods 42 and interior supporting rods 44 are arranged. Both the exterior supporting rods 42 and the interior supporting rods 44 are arranged evenly along circular lines. An algal substrate 46 extends between the supporting rods 42 and 44 in the shape of a thin nonwoven sheet material 48 extending alternately around the exterior and the interior rods 42, 44, i. e., in the shape of a star or substantially similar to the shape of a star. Gas 50 is fed into the frame 32 from below so that it flows along the individual vertical substrate surfaces 52 extending in the direction of the flow of the gas.

A driving means 54 for rotatably driving the body of rotation 38 is arranged on the horizontal struts 36 of the frame. In the case represented in Figs. 2 and 3, the driving means 54 comprises an impeller 56. The rotational axis 58 of the driving means 54 comprises a knuckle joint 60 connected to the rotational axis 62 of the body of rotation 38. In this way, the body of rotation 38 also rotates when it is set into an oscillating motion by lateral forces (wind forces, for instance).

One of the vertical struts 34 comprises a nutrient supply means 64 comprising individual nozzles 66 by which a nutrient pumped from a reservoir 68 is sprayed against the substrate moving past the nutrient supply means 64. The reactor 30 according to Figs. 2 and 3 can, as in the case of Fig. 1, be supplemented to feed the nutrient in circulation. However, it is advantageous to design the supply means such that a sufficient quantity of nutrient medium is permanently sprayed on the substrate without excess nutrient medium dripping off.

As is shown in Fig. 2, parts of the substrate 46 are always exposed to direct solar radiation 70 when the body of rotation 38 rotates in the direction of the arrow 72. The subsequent individual substrate surfaces 52 arranged in a lamellar shape shade off one another in partial areas during the rotational

movement of the substrate 46 or only allow for an exposure to diffuse sunlight (weak light). This alternate direct exposure, shading and diffuse exposure avoids that a photo inhibition of the algae fixed to the sheet material 64 can arise so that the algae can always regenerate for an optimum photosynthesis. An additional partial shading can optimize this effect.

By means of substrate surfaces 52 arranged obliquely to the flow of the gas 40, it would be possible to use the gas flow to rotate the body of rotation 38. Thus, in this case, both the gas flow and the wind could be used as a rotational drive.

Now the construction of a reactor 80 according to another embodiment of the invention will be described in detail with reference to Fig. 3. This reactor 80 comprises an upper plate 82 connected, by means of a rotational axis 84, to a congruent lower plate which is not represented in the top plan view according to Fig. 4. The upper plate 82 is mechanically reinforced by reinforcement struts 86. Extractable inserts 88 are located between adjacent struts 86 in the plate 82, the inserts comprising a semicircular supporting arc 90. Identical semicircular supporting arcs 90 are also arranged on the lower plate of the reactor 80; these supports are also arranged on inserts of the lower plate. The nonwoven algal substrate 92 is arranged between the semicircular supports of the two plates and is held under tension as an endless loop on both sides of the semicircular supporting arcs 90. Each insert 88 of the upper plate 82 further comprises two recesses 94, 96, the recess 94 being semicircular and limited by the supporting arc 90 as well as the strut 86 directed towards the interior side of this supporting arc 90. The second recess 96 is arranged between the vertex of the supporting arc 90 of a recess 88 and the strut 86 directed towards the outside of the supporting arc 90. In addition to that, a central nutrient medium supply channel system 98 is arranged on the plate 86 and comprises an annular distribution channel and radial channels branching off radially therefrom leading towards the supporting arcs 90 and guiding the nutrient medium to the substrate 92.

The arc-shaped algal substrate foils 96 are arranged freely between the plates connected to each other by means of the rotational axis 84 (only the upper plate 82 is shown in Fig. 4). The semicircular algal substrate foils 82 work like the rotor blades of a rotor which is rotated by the wind flowing by according to the arrow 100. The sunlight partially impinges through the laterally open area of the reactor 80 and from above through the recesses 94 and 96 in the plate 82 of the reactor 80.

CLAIMS

1. Rotating solar photo bioreactor for producing algal biomass especially from gases containing carbon dioxide, comprising:

   - a frame (17; 32),

   - an algal substrate (46; 92) for algae, which is pivoted about a vertical rotational axis (62; 84) on the frame (17; 32) and whereon the algae remain during the growth thereof and which is intermittently exposable to sunlight of varying intensity,

   - a driving means (54) for rotatably driving the algal substrate (46; 92) with the surface of the algal substrate (46; 92) extending substantially parallel to the vertical rotational axis (62; 84), and

   - a nutrient medium supply means for supplying a nutrient medium to the algal substrate (46; 92).

2. Rotating solar photo bioreactor according to claim 1, characterized in that the algal substrate (46; 92) is a thin sheet material supported by a supporting structure (42, 44; 82).

3. Rotating solar photo bioreactor according to claim 2, characterized in that the supporting structure comprises a cage with parallel exterior supporting rods (42) arranged along an exterior circumference line and with interior supporting rods (44) parallel to the exterior supporting rods (42) and arranged along an interior circumference line, the sheet material (48) extending between the interior and exterior supporting rods (42, 44) and around these and being supported by the cage.

4. Rotating solar photo bioreactor according to any one of claims 1 to 3, characterized in that the driving means (54) drives an impeller (56).

5. Rotating solar photo bioreactor according to claim 4, characterized in that the algal substrate is formed as an impeller or a vane wheel for being rotatably driven by wind.

6. Rotating solar photo bioreactor according to any one of claims 1 to 7, characterized in that the driving means is a solar driving means.

7. Rotating solar photo bioreactor according to any one of claims 1 to 3, characterized in that the algal substrate is formed as a vane wheel for rotating due to gas flowing past the algal substrate.

8. Rotating solar photo bioreactor according to any one of claims 1 to 7, characterized in that the nutrient medium supply means (64; 98) covers at least part of the algal substrate (46; 92), with the entire surface of the algal substrate (46; 92) being able to be humidified by nutrient medium per rotation when the algal substrate (46; 92) is rotated.

9. Rotating solar photo bioreactor according to any one of claims 1 to 8, characterized in that the algal substrate (46) is suspended on gimbals (60) on the frame (36).

10. Rotating solar photo bioreactor according to any one of claims 1 to 9, characterized in that a shading member having at least one window for passing sunlight to the algal substrate (46; 92) is provided.

11. Rotating solar photo bioreactor according to claim 10 or 11, characterized in that the shading member is able to track the incident sunlight depending on the time of day.

12. Rotating solar photo bioreactor according to any one of claims 10 to 12, characterized in that the shading member comprises a plurality of windows.

13. Rotating solar photo bioreactor according to claim 10, characterized in that at least one optical member for concentrating the incident sunlight on the algal substrate is provided for each window.

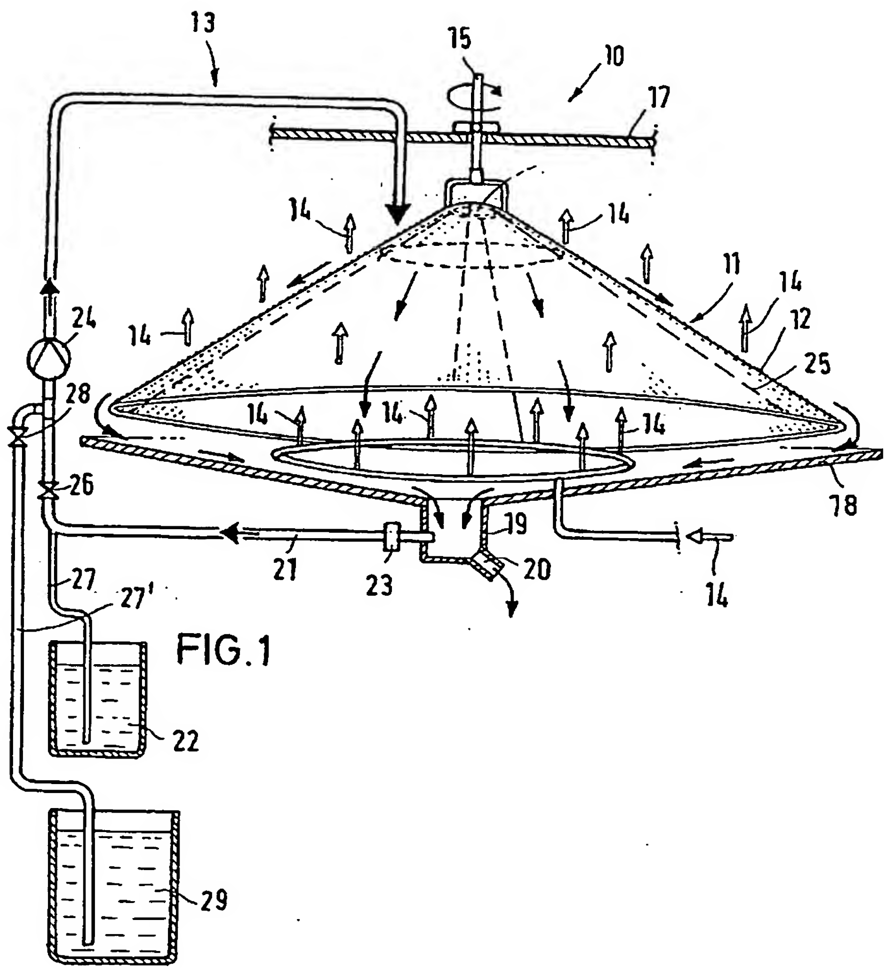
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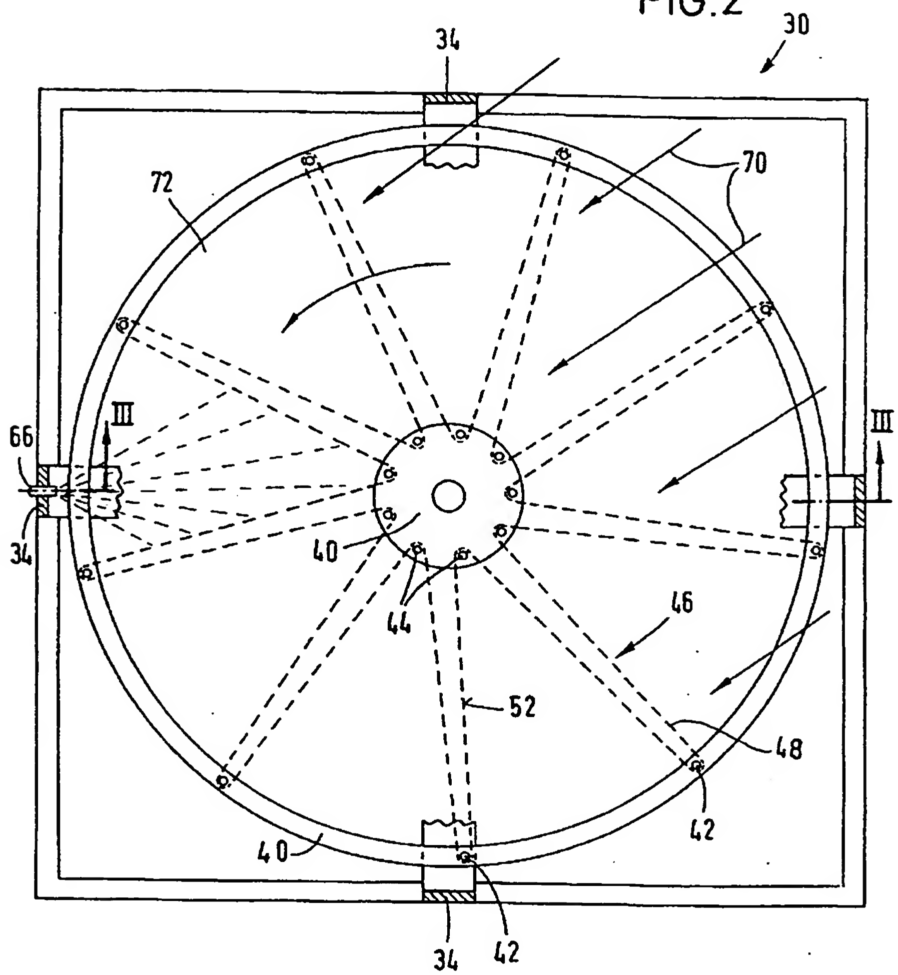
FIG.1

FIG.2



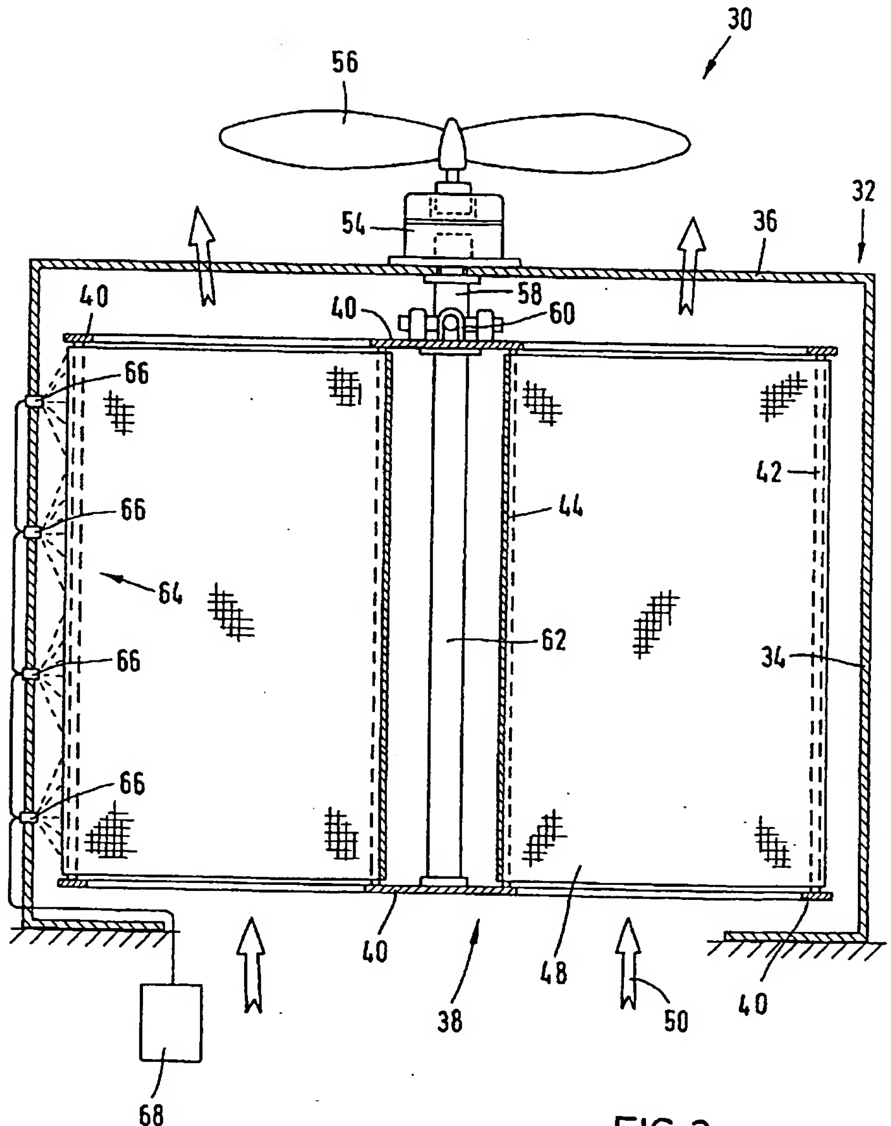


FIG.3

FIG.4